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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 5 : G03F 1/14, 7/09

A1

(11) International Publication Number: WO 94/17450

(43) International Publication Date: 4 August 1994 (04.08.94)

(21) International Application Number: PCT/US93/12094

(22) International Filing Date: 13 December 1993 (13.12.93)

(30) Priority Data:

08/007,638	21 January 1993 (21.01.93)	US
08/007,640	21 January 1993 (21.01.93)	US

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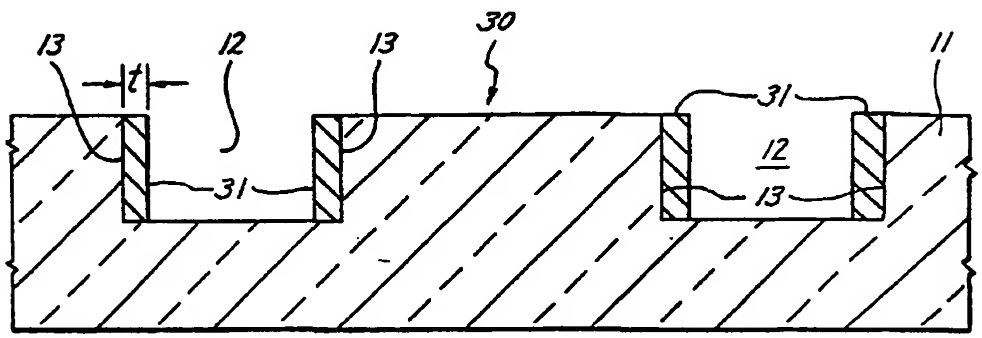
(81) Designated States: AT, AU, BB, BG, BR, BY, CA, CH, CZ, DE, DK, ES, FI, GB, HU, JP, KP, KR, KZ, LK, LU, LV, MG, MN, MW, NL, NO, NZ, PL, PT, RO, RU, SD, SE, SK, UA, UZ, VN, European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG).

Published

With international search report.

(54) Title: PHASE SHIFTING MASK STRUCTURE WITH ABSORBING/ATTENUATING SIDEWALLS FOR IMPROVED IMAGING AND METHOD OF FABRICATING PHASE SHIFTERS WITH ABSORBING/ATTENUATING SIDEWALLS



(57) Abstract

A phase shifting mask has phase shifters in which the sidewalls of the shifters are coated with a light absorbing or attenuating material. The light absorption at the sidewalls reduces the edges scattering and improves the resolution by obtaining similar transmission profiles from phase shifted and unshifted regions of the PSM. A method of fabricating phase shifters with absorbing or attenuating sidewalls in order to inhibit or prevent light scattering at quartz-air interfaces is also provided. A quartz substrate is patterned and trenches are formed to provide "shifters". A metal film layer is formed along sidewalls of the trenches to provide the light absorbing characteristics. In one technique, the conformal metal layer is anisotropically etched while in another the metal layer is removed along with the photoresist by a lift-off technique.

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DESCRIPTION

PHASE SHIFTING MASK STRUCTURE WITH ABSORBING/ATTENUATING SIDEWALLS FOR IMPROVED IMAGING AND METHOD OF FABRICATING PHASE SHIFTERS WITH ABSORBING/ATTENUATING SIDEWALLS

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to the field of fabricating photomasks for use in the manufacture of semiconductor devices and, more particularly, to the fabrication of phase shifting photomasks for use in submicron lithography techniques.

2. Prior Art

Various techniques are known in the prior art for manufacturing devices on a semiconductor wafer, such as a silicon wafer. Typically, lithography processes are utilized to overlay a pattern(s) onto the wafer. Each pattern provides for selected portions of the wafer to undergo a particular lithographic process, such as deposition, etch, implant, etc. Photomasks (masks) are generally utilized to overlay a particular pattern on the wafer or a layer formed on the wafer. Generally a number of these masks are required for manufacturing a complete device on the wafer.

The earlier prior art lithography techniques rely upon optical techniques in which light is passed through a mask to overlay a pattern on the wafer. Generally, a pattern on the mask equated to a pattern design appearing on the surface of the wafer. However, as the semiconductor technology evolved to allow ever smaller

device structures to be fabricated on a wafer, it became increasingly difficult to continue to use the standard optical techniques. It is generally theorized that as device features approach submicron dimensions of 0.25 microns and below, alternative techniques would be required to project patterns onto a wafer.

Due to the limitation imposed by the wavelength of light, resolution at the edges of these patterns tend to degrade when ordinary optical techniques are employed. Standard optical techniques utilizing ultra violet (UV) light will extend the lower range, but still fall short of desired resolution at extremely low ranges (under 0.25 microns). It was generally believed that technologies employing shorter wavelength would ultimately be required for lithography. A number of approaches have been suggested with x-ray lithography being viewed as the technology for use at these low submicron ranges.

However, recent experimentation in the area of phase shifting masks (PSMs) have shown that the PSM technology can be employed to extend the range of optical techniques currently being utilized. That is, the current I-line (at a wavelength of 356 nanometers) and deep ultra violet, or DUV (at a wavelength of 248 nanometers), optical photolithography techniques can be used with the phase shifting photomasks to provide the requisite resolution with sufficient depth of focus for fabricating semiconductor devices having dimensions in the order of .25 microns and below. It is believed that resolutions in the order of 0.1 micron resolution levels can be obtained with sufficient focus latitude by the use of ordinary lithography techniques when phase shifting techniques are applied.

It is generally understood that the technique for improving resolution in photolithography by the use of

phase-shifting masks was first proposed by Levenson et al., ("Improving Resolution in Photolithography with a Phase-Shifting Mask", IEEE Transactions on Electron Devices, Vol. ED-29, No. 12, December 1982, pp. 1828-1836) and later implemented by Terasawa et al. ("0.3-micron optical lithography using a phase-shifting mask", Proceedings of SPIE, Vol. 1088 Optical/Laser Microlithography II, 1989, pp. 25-32).

The conventional PSM comprises of creating phase shifting regions in the transparent areas of a photomask. These phase-shifting regions are formed either by depositing transparent films of appropriate thickness and then patterning them over the desired transparent areas using a second level lithography and etch technique or by etching vertical trenches into the quartz substrate. In both of these instances, the "edges" or ("walls") between the phase shifted and unshifted regions mostly result in a transition between high and low refractive index regions.

This sharp transition of the refractive index and the three dimensional structure cause scattering of light due to internal reflections at the edges and causes the transmitted light intensity and spatial profile to vary between the shifted region and the unshifted region and leads to the "waveguiding" effect. The "waveguiding" effect results in the "funnelling" of light into a narrower region in the "phase shifted" areas thereby causing nonuniformity in the aerial image spatial profiles. Consequently, the imaging characteristics of conventional PSMs and uniformity of line- widths are degraded and is less than optimum. This degradation in linewidth uniformity also leads to problems with maintaining a desired aerial image in exposure characteristics across an entire field.

It is appreciated that a technique that would reduce the scattering of light at the transition regions and eliminate the waveguiding effect would provide for a PSM having improved image and exposure characteristics, as well as maintaining a desired uniformity of linewidths across the entire printed image field.

SUMMARY OF THE INVENTION

A PSM structure having absorbing/attenuating sidewalls along the shifter region in order to improve resolution, linewidth uniformity and depth of focus is described. The PSM of the present invention utilizes shifters in which trenches are formed in a quartz substrate to provide the 180° phase shift. However, the invention can be readily extended to deposited film shifters as well.

Once the trenches are patterned and formed in the quartz, the sidewalls of the trenches are coated with a light absorbing or attenuating material. The scattering effect experienced at these edges in the prior art PSM are now reduced or eliminated due to the absorption of the light by the sidewalls in the PSM of the present invention. This absorption of light at the sidewalls also creates a "lossy" waveguide thereby eliminating the resonances and hence eliminating the waveguiding effect.

Further, a method of fabricating phase shifters with absorbing/attenuating sidewalls in order to improve resolution, linewidth uniformity and depth of focus in a PSM is described.

After the trenches are patterned and formed, a conformal metal layer is deposited over the substrate, including the trench regions. Then, anisotropic dry

etching removes the metal layer except for the vertical area adjacent to sidewalls of the trenches. The absorbing/attenuating sidewall inhibits or prevents scattering of light at the sidewall region when light transitions across the quartz-air interface of the PSM. The absorbing sidewall is shown being formed on an unattenuating PSM and on a Levenson-type PSM. However, it is applicable to other types of PSM as well.

In an alternative method, the conformal metal layer is deposited prior to the removal of the patterned photoresist. Then, a "lift-off" technique is used in which the photoresist is removed by dissolution using a shaking or an agitating action in a liquid solvent. The metal layer overlying the photoresist is removed along with the photoresist breaking away from the entire film so that only the metal layer in the trenches remain.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1A is a cross-sectional diagram showing a prior art PSM using a quartz substrate with trenches formed therein as shifters.

Figure 1B is a cross-sectional diagram of the PSM of Figure 1A and showing transmission of light therethrough, including the scattering experienced at edges of the trench.

Figure 2A is a cross-sectional diagram showing a PSM of the present invention in which a light absorbing sidewall is formed in trench regions to reduce the scattering.

Figure 2B is a cross-sectional diagram of the PSM of Figure 2A and showing transmission of light therethrough, including the absorption at the trench sidewalls.

Figure 3 is a graphic illustration comparing light intensity profiles for the PSMs shown in Figures 1 and 2.

Figure 4A is a cross-sectional diagram showing a quartz substrate used in forming an unattenuated PSM of the present invention.

Figure 4B is a cross-sectional diagram showing a formation of patterned photoresist atop the substrate of Figure 4A.

Figure 4C is a cross-sectional diagram showing a formation of trenches in the substrate of Figure 4B which are utilized to form "shifter" regions.

Figure 4D is a cross-sectional diagram showing a formation of a conforming metal layer over the substrate once the photoresist is removed from the illustration of Figure 4C.

Figure 4E is a cross-sectional diagram showing absorbing sidewalls once the metal layer of Figure 4D is anisotropically etched.

Figure 5A is a cross-sectional diagram showing chromium blanks atop a quartz substrate used in forming a Levenson type PSM of the present invention.

Figure 5B is a cross-sectional diagram showing a formation of a patterned photoresist atop the substrate and the blanks of Figure 5A.

off" process is used to remove the photoresist of Figure 7B.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

A phase shifting mask (PSM) with light absorbing or attenuating sidewalls is described. In the following description, numerous specific details are set forth, such as specific structures, layers, materials, etc., in order to provide a thorough understanding of the present invention. However, it will be obvious to one skilled in the art that the present invention may be practiced without these specific details. In other instances, well known processes and structures have not been described in detail in order not to unnecessarily obscure the present invention.

Referring to Figures 1A and 1B, a prior art conventional phase shifting mask (PSM) 10 utilizing a vertical trench as a shifter is shown. PSM 10 is a simple unattenuated mask having a glass or quartz substrate 11 with openings 12 (which are also commonly referred to as trenches) formed in quartz 11. The region formed by each trench 12 provides sidewalls 13 which have a specified vertical depth denoted as distance "d" in Figure 1A. The open trench 12 is typically in air, which has an index of refraction of 1.0, while the quartz substrate 11 typically has an index of refraction of approximately 1.5. Light traversing through substrate 11 and trench 12 (denoted by light ray 15 in Figure 1B) will be out of phase in comparison to a light ray traversing completely through substrate 11 (as denoted by ray 16 in Figure 1B). That is, the phase of light ray 15 is shifted by some phase angle (usually 180°) when compared to the phase of ray 16. The resulting phase shift is

Figure 5C is a cross-sectional diagram showing a formation of a trench in the substrate of Figure 5B which is utilized to form a "shifter" region.

Figure 5D is a cross-sectional diagram showing a formation of a conforming metal layer over the substrate once the photoresist is removed from the illustration of Figure 5C.

Figure 5E is a cross-sectional diagram showing absorbing sidewalls once the metal layer of Figure 5D is anisotropically etched.

Figure 6A is a cross-sectional diagram showing trench formation after photo resist patterning in fabricating an unattenuated PSM.

Figure 6B is a cross-sectional diagram showing a formation of a conforming metal layer over the substrate and photoresist of Figure 6A.

Figure 6C is a cross-sectional diagram showing the remaining metal layer in the shifter trenches after a "lift-off" process is used to remove the photoresist of Figure 6B.

Figure 7A is a cross-sectional diagram showing trench formation after photoresist patterning in fabricating a Levenson type PSM.

Figure 7B is a cross-sectional diagram showing a formation of a conforming metal layer over the substrate, blanks and photoresist of Figure 7A.

Figure 7C is a cross-sectional diagram showing the remaining metal layer in the shifter trench after "lift-

achieved by the presence of trench 12. Therefore, each trench 12 functions as the phase shifter and is typically referred to as a "shifter" for the prior art PSM 10.

In Figure 1B, the "edge" and "edge scattering" problem associated with prior art PSM 10, leading to undesirable internal reflections, is exemplified. Light rays, such as rays 15-18 traverse through mask 10 at a substantially perpendicular angle to the transitioning edge 14 of mask 10. These rays 15-18 have the minimum scattering effects. Even rays which are not normal to edge 14, such as rays 20-22, provide minimum of scattering effects. However, light rays, such as rays 25-28, which reach the sidewalls 13 can result in considerable scattering due to the angle of incidence of light striking the edge formed by the sidewalls. At times, this edge scattering can result in significant degradation to the lithography resolution, thereby noticeably affecting the image and exposure characteristics.

Furthermore, the scattering at the edges can cause nonuniformity in linewidths of the printed image. For example, in Figure 1B, distortions in the linewidth of the printed image due to distortions from the shifter regions, are shown as widths w_1 and w_2 and are the result of edge scattering and "waveguiding" effects. These distortions, depicted by w_1 and w_2, can then result in nonuniformity of the lines projected on the printed image.

Referring to Figures 2A and B, a phase shifting mask 30 of the present invention is shown. PSM 30 is formed similarly to that of the prior art mask described in Figures 1A-B, however, mask 30 now includes a light absorbing or attenuating sidewall 31 to address the scattering problem noted with the prior art PSM 10 of

Figures 1A-B. The absorbing/attenuating sidewall 31 is disposed along the vertical ("sidewall") portion of trench 12. The absorbing/attenuating sidewall 31 is formed from a conducting material in order to provide a conducting region to fully absorb or attenuate (partially absorb in order to attenuate) light rays penetrating the sidewall. This aspect of the invention is better illustrated in Figure 2B.

Using the same reference numerals associated with the light rays depicted in Figure 1B, Figure 2B shows what actually happens to the light rays 25-28 which impact the sidewall 31. Instead of scattering due to the edge effects of the sidewall, these rays 25-28 are substantially absorbed by the absorbing sidewall 31. The light is fully absorbed (shown by rays 25 and 27) or partially absorbed so that the light is attenuated (shown by rays 26 and 28). The absorption of light by absorbing sidewalls 31 altogether prevents or reduces the scattering problem encountered with the prior art PSM 10. Thus, it prevents or inhibits total internal reflections and especially for partially coherent illumination, eliminates the "waveguiding" effects by creating "lossy" sidewalls which suppress resonances on the shifted regions. The elimination of waveguiding using "lossy" sidewalls also makes the spatial profiles independent of shifter width or depth (i.e., removes geometrical dependance).

Referring to Figure 3, a graphic illustration comparing the light intensity between the phase shifted and unshifted regions for the conventional PSM 10 and PSM 30 of the present invention utilizing the absorbing sidewall 31 is shown. On the abscissa, distance left of the origin depict the phase-shifted region (i.e., the presence of trench 12), while the unshifted region (i.e., absence of trench 12) is depicted to the right of the

origin. The edge is shown as the origin with distances shown in 10^{-6} meters. The ordinate provides the amplitude of relative light intensity.

Two conditions are shown in the graph of Figure 3. Curve 40 shows the intensity profile of the aerial image projected onto the target, such as a semiconductor wafer without the absorbing sidewall 31, while curve 41 shows equivalent intensity profile but with the presence of the absorbing sidewall 31. Without the absorbing/attenuating sidewall 31, the prior art PSM 10 results in the difference 42 of the two intensity profiles. This difference can degrade the resolution and/or the depth of focus of the aerial image as well as causing a nonuniformity of linewidth in the printed image. However, with the absorbing sidewall 31, the PSM 30 of the present invention is shown having fairly equal intensity profiles for both the phase-shifted and unshifted regions.

The particular example of Figure 3 is that of a chromeless glass PSM operating at DUV wavelength of 245 nm with 5x magnification where σ (partial coherence) = 0, NA (numerical aperture) = 0.5 and df (depth of focus) = 0. The material for the absorbing sidewall 31 is chromium (Cr) having a thickness t of approximately 200 angstroms.

It is to be noted that a variety of conducting materials can be readily utilized to form the absorbing/attenuating sidewall 31 of the present invention. However the preferred material is metal, metal alloy or silicide. The design criteria is that the absorbing factor (K) of the metallic material, which is known by $K=4\pi\sigma/\lambda$, where σ is electrical conductivity and λ is the wavelength of light, should be such that the incoming light intensity (I_o) is reduced to 1/e of its

value within a thickness t (t being the thickness of the absorbing sidewall 31 as is noted in Figure 2A). The thickness t is commonly referred to as the "skin" depth and typical values vary within a range of 100 to 500 angstroms for most conducting materials over the wavelength range from deep ultraviolet to I-line and thereby can be present without significantly perturbing the forward transmission characteristics of the PSM 30.

It is to be appreciated that various light absorbing materials which are typically conducting materials, can be utilized for the absorbing sidewall 31 of the present invention, as is noted in the description above. Typical example materials are molybdenum, chromium, aluminum and gold, as well as their alloys and silicides. Silicon can also be utilized but provides less absorption than metals for comparable thicknesses. An advantage of using silicon is that it is easier to deposit and etch than metallic materials and the thickness control is less stringent. The thickness t of these materials should be of appropriate value to allow sufficient absorption of light at the wavelength of interest for a given light intensity, as was noted above. For metals, thickness t would be toward the lower end of the range (100 angstroms) while thickness t for silicon will be toward the middle and upper end of the range (300 - 500 angstroms).

The presence of such a metallic or silicon coating along the sidewall of trench 12 provides for a number of advantages. These advantages include improving the imaging characteristics of the PSM by reducing sidewall scattering, reducing "waveguiding" effects, improving resolution, and improving the depth of focus (by making the aerial image conform closer to the ideal. Other advantages include improving repairability of masks in a repair system (such as a Focussed Ion Beam or Laser

Repair System) by providing a conductive coating at edges and improving edge detection and contrast in inspection systems. The conductive layer provides an etch "stop" for stopping the ion beam milling process with excellent selectivity.

The reason for this is that the optical "contrast" in an ion-beam mask repair system is significantly enhanced by a glass-to-metal transition than a glass-to-glass transition. Furthermore, the PSM 30 of the present invention is fairly easy to fabricate.

It is to be appreciated that although a particular PSM 30 has been described herein, absorbing sidewalls 31 using conductive and semiconductive materials can be readily implemented in a variety of situations involving PSMs. It is to be further appreciated that although PSM 30 is shown as a conventional unattenuated PSM, the present invention can be readily utilized with other types of PSMs, such as Levenson, Rim, subresolution and attenuated PSMs, without departing from the scope and spirit of the present invention. Thus, this invention can be readily extended to deposited film shifters as well.

A number of techniques can be utilized to form the absorbing/attenuating sidewall 31. Metallic, as well as silicon material can be deposited into the trench 12 of the prior art PSM 10 and anisotropically etched in order to form the absorbing sidewall 31 of the present invention. However, the preferred method for forming such an absorbing sidewall is disclosed below.

A method for fabricating phase shifters with absorbing or attenuating sidewalls using an additive process is described. In the following description, numerous specific details are set forth, such as specific

structures, layers, materials, etc., in order to provide a thorough understanding of the present invention. However, it will be obvious to one skilled in the art that the present invention may be practiced without these specific details. In other instances, well-known processes and structures have not been described in detail in order not to unnecessarily obscure the present invention.

Furthermore, the method described herein can be readily adapted for forming a variety of light absorbing or attenuating layers, but the preferred application is for the purpose of forming light absorbing/attenuating sidewalls along trench sidewalls of phase shifting masks (PSMs). A PSM utilizing a trench shifter which includes a light absorbing/attenuating sidewall has been described above.

Referring to Figures 4A-E, a method for forming a phase shifter having conducting sidewalls for light absorption or attenuation in an unattenuated photomask is illustrated. The unattenuated photomask 10a is formed from a quartz substrate 11a which generally has an index of refraction of 1.5. Then, a layer of photoresist 12a is formed on the quartz substrate 11a, and patterned using standard lithography techniques in order to form patterned openings 13a which expose the underlying substrate 11a. Subsequently, a dry etching process (preferably one using a fluorine chemistry), such as a process utilizing carbon tetrafluoride (CF_4) plasma, is used to etch an opening 14a (also referred to as a trench) into substrate 11a to a depth "d_1" as noted in Figure 4C.

Trench 14a cuts into the substrate 11a and thereby forms a phase shifter of mask 10a. Then, the remaining photoresist 12a is then stripped. Afterwards, a thin

film layer of metallic absorber material 17a is conformally deposited over the substrate 11a and trench 14a, as shown in Figure 4d. Sidewalls 18a of trench 14a also are covered by the metallic material 17a. Typically, thickness t_1 of the metallic absorbing layer 17a is in the order of approximately 100 to 500 angstroms. Conformal deposition of layer 17a can be readily achieved by chemical vapor deposition (CVD), sputtering (such as collimated sputtering) or by evaporation of metal.

Finally, a subsequent etching technique, such as a sputter etch in argon (Ar^+) plasma or, alternatively, an reactive ion etching (RIE) technique using Chlorine or the appropriate chemistry is used to anisotropically remove the metallic film 17a, including the film located at the bottom of the trench. The anisotropic etching removes all of metal layer 17a except for a portion adjacent to sidewalls 18a due to its vertical profile. Thus, an edge coating remains along the sidewalls 18a forming absorbing/attenuating sidewall layer 17a within trench 14a. This type of anisotropic etching occurs naturally in RIE etch equipment. The RIE etch process adjusted for the metal film stops on the quartz substrate 11a such that precise control of etching time or introduction of etch stops are not required. In sputter etching, the selectivity is high due to the considerable difference in the sputter rates of metal versus quartz. Thus, the resultant absorbing sidewall 19a for preventing or reducing (attenuating) edge scattering at the sidewall is formed.

Referring to Figures 5A-E, a formation of a light absorbing/attenuating sidewall on an Levenson-type PSM 10b is described. The process is similar to that described in reference to unattenuated PSM 10a of Figures 4A-E with the difference that the Levenson PSM 10b

employs chromium (Cr) regions 20b atop the quartz. These chromium regions (blanks) 20b are also referred to as opaque regions in standard binary intensity masks. The formation of a chromium film of approximately 1000-2500 angstroms is formed and patterned on the quartz substrate 11b. As in the earlier process, a photoresist is formed over the substrate 11b and chromium opaque region 20b. However, as is noted in Figure 5B, it is not critical to have the edge of the photoresist define the location of trench 14b since the edges of the chromium blank 20b will define the edge location by self-alignment. In the particular example of Figure 5B, photoresist 12b is patterned to have an opening 13b only between two of the chromium blanks 21b and 22b, while the photoresist layer 12b completely covers the other separation between the chromium blanks 22b and 23b.

Subsequently, using a dry-etch process, trench 14b is formed into quartz 11b. The sidewalls 18b of trench 14b are aligned with the edge of the two chromium blanks 21b and 22b. Due to the presence of the photoresist 12b an opening is not formed between chromium blanks 22b and 23b. Next, the photoresist layer 12b is removed by using a strip process. Then the conforming metal layer 17b is deposited over both the substrate 11b, including trench 14b, and over chromium blanks 20b by one of the processes described earlier. Then using either of the sputter etch or the RIE etch techniques, metal film 17b is anisotropically removed leaving a metal layer 17b only adjacent to vertical sidewalls 18b to form absorbing sidewalls 19b. Thus, absorbing/attenuating sidewalls 19b are formed within trench 14b and only adjacent to the sidewalls 18b. The thickness t_2 of the sidewalls 19b are equivalent to that of t_1, earlier described.

Referring to Figures 6A-C and 7A-C, methods for forming an absorbing sidewall using an alternative "lift-

off" process for the unattenuated and Levenson-type PSMs are shown. In Figure 6A, trench opening 14c is formed in substrate 11c by the process described in reference to Figures 4A-1C. Subsequently, instead of removing the photoresist 12c, metal film layer 17c is deposited over both the photoresist 12c and substrate 11c at or near room temperature. The conformal metal layer is deposited by collimated sputtering as shown in Figure 6B.

Next, the photoresist 12c is dissolved in a hot developer (or other liquid solvent) while a shaking or agitating force is used to break the photoresist 12c and metal film 17c located atop the photoresist 12c. The photoresist 12c and its overlying metal film 17c breaks and is dislodged from the quartz 11c. As is noted in Figure 6C, once the photoresist 12c and the overlying metal layer 17c are removed, only the metallic coating within trenches 14c remain. Thus, the phase shifters of PSM 10c formed by trenches 14c will have a metallic layer 17c on the entire shifter surface, and not only along the sidewalls 18c.

It is to be noted that the "lift-off" process can be utilized when the film has a thickness toward the lower end of the range. It is preferred that the thickness of metal film 17c be kept at under 150 angstroms for the "lift-off" method to be used. Because of this smaller thickness, absorption of light at the bottom of the trench (due to the bottom film layer) is kept to a minimum.

Figures 7A-C show a similar process but on the Levenson-type PSM 10d which employs chromium blanks 20d. A photoresist layer 12d is formed overlying portions of substrate 11d and blanks 20d. Again, as was noted earlier in reference to Figures 5A-E, the actual location of the edge of the photoresist 12d defining the trench

14d is not as critical in the Levenson-type PSM since pads 21d and 22d define the sidewalls 18d for trench 14d. Figure 7A shows the process as described in reference to Figures 5A-C.

Subsequently, prior to the removal of the photoresist 12d, a metal film layer 17d is deposited above substrate 11d, chromium blanks 20d and photoresist 12d, as is shown in Figure 7B. Again, the resist is dissolved in a hot developer with the aid of a shaking or agitating action to break the photoresist 12d and metal film 17d overlying the photoresist 12d. The removal of the photoresist 12d and the overlying metal layer 17d essentially leaves only the metal conformal layer within trench 14d. Thus, the metal layer 17d is present along the sidewalls 18d and at the base of the trench 14d which forms the shifter portion of the PSM 10d. Again, this "lift-off" process is available for film thicknesses of under 150 angstroms.

The various types of materials for use in forming the absorbing sidewall 19a-d is a design choice and is noted above. Preferred materials are conducting materials, such as molybdenum, chromium, aluminum, gold, their alloys and silicides. Silicon can also be utilized, but its thickness must be appropriately designed.

It is to be appreciated that absorbing/attenuating sidewalls can be readily implemented in variety of situations involving PSMs. It is to be further appreciated that the present invention can be readily utilized with other types of PSMs, such as Rim, subresolution and attenuated PSMs, without departing from the scope and spirit of the present invention. For example, in the case of attenuating PSMs, the method described herein can be used for both the opaque regions

as well as sidewall absorbers in a single lithography step.

Thus, a phase shifting mask structure with absorbing/attenuating sidewalls for improved imaging is described and a method of fabricating a phase shifting mask invention with absorbing/attenuating sidewalls or attenuating phase shifters for improved imaging is described.

CLAIMS

1. A photolithography mask having a portion of said mask for phase shifting incident light transmission therethrough as compared to other portions of said mask comprising:

a substrate having at least one vertical trench formed therein, wherein said trench functions to phase shift incident light transmission therethrough;

conductive regions being formed along sidewalls of said vertical trench for absorbing at least a portion of light energy impinging on said sidewalls;

wherein said conductive regions inhibit light scattering at said sidewalls in order to improve resolution of a projected image field.

2. The photolithography mask of Claim 1 wherein said conductive regions are formed from a metallic material.

3. The photolithographic mask of Claim 1 wherein said conductive regions are formed from a material selected from a group consisting of molybdenum, chromium, aluminum, gold, their alloys and their silicides.

4. The photolithography mask of Claim 1 wherein said conductive regions are formed from silicon.

5. A photolithography mask, having portions of said mask for phase shifting incident light transmission therethrough as compared to other portions of said mask, for projecting an image pattern utilizing phase shifted techniques comprising:

a substrate having a plurality of vertical trenches formed therein, wherein said trenches function to phase shift incident light transmission therethrough;

conductive regions being formed along sidewalls of said vertical trench for absorbing light energy impinging on said sidewalls;

wherein said conductive regions inhibit light scattering at said sidewalls in order to improve resolution and provide uniformity of linewidth in said image pattern.

6. The photolithography mask of Claim 5 wherein said substrate is formed from a dielectric material.

7. The photolithography mask of Claim 6 wherein a thickness of said conductive regions is in the range of 100-500 angstroms.

8. The photolithography mask of Claim 7 wherein said conductive regions are formed from a metallic material.

9. The photolithographic mask of Claim 7 wherein said conductive regions are formed from a material selected

from a group consisting of molybdenum, chromium, aluminum, gold, their alloys and their silicides.

10. The photolithography mask of Claim 7 wherein said conductive regions are formed from silicon.

11. A photolithography mask, having portions of said mask for phase shifting incident light transmission therethrough as compared to other portions of said mask, for projecting an image pattern utilizing phase shifted techniques comprising:

a substrate having a plurality of vertical trenches formed therein, wherein said trenches function to phase shift incident light transmission therethrough;

conductive regions being formed along sidewalls of said vertical trench for attenuating light energy impinging on said sidewalls;

wherein said conductive regions inhibit light scattering at said sidewalls in order to improve resolution and provide uniformity of linewidth in said image pattern.

12. The photolithography mask of Claim 11 wherein said substrate is formed from a dielectric material.

13. The photolithography mask of Claim 12 wherein a thickness of said conductive regions is in the range of 100-500 angstroms.

14. The photolithography mask of Claim 12 wherein said conductive regions are formed from a metallic material.

15. The photolithographic mask of Claim 12 wherein said conductive regions are formed from a material selected from a group consisting of molybdenum, chromium, aluminum, gold, their alloys and their silicides.

16. The photolithography mask of Claim 12 wherein said conductive regions are formed from silicon.

17. A method of fabricating a phase shifting photomask comprising the steps of:

forming a patterned photoresistive layer over a substrate in which patterned openings expose portions of said underlying substrate;

etching said exposed portions of said substrate to form vertical trenches in said substrate, said trenches functioning as phase shifting regions of said photomask;

removing said photoresistive layer;

depositing a thin film layer over said substrate; including within said vertical trenches;

etching said thin film layer such that said thin film layer substantially remains only on sidewall surfaces of said trenches;

wherein said thin film layer is utilized for absorbing at least a portion of light energy

impinging on said sidewalls in order to inhibit light scattering at said sidewalls such that resolution of a projected image field of said photo mask is improved.

18. The method of Claim 17 wherein said thin film layer is deposited to a thickness of 100-500 angstroms.

19. The method of Claim 18 wherein said thin film layer is formed from a metallic material.

20. The method of Claim 18 wherein said thin film layer is formed from a silicon material.

21. A method of fabricating a phase shifting photomask comprising the steps of:

forming a patterned photoresistive layer over a substrate having opaque regions disposed thereon and in which patterned openings expose portions of said underlying substrate;

etching said exposed portions of said substrate to form vertical trenches in said substrate, said trenches functioning as phase shifting regions of said photomask;

removing said photoresistive layer;

depositing a thin film layer over said substrate, including within said vertical trenches;

etching said thin film layer such that said thin film layer substantially remains only on sidewall surfaces of said trenches;

wherein said thin film layer is utilized for absorbing at least a portion of light energy impinging on said sidewalls in order to inhibit light scattering at said sidewalls such that resolution of a projected image field of said photo mask is improved.

22. The method of Claim 21 wherein said thin film layer is deposited to a thickness of 100-500 angstroms.

23. The method of Claim 22 wherein said thin film layer is formed from a metallic material.

24. The method of Claim 22 wherein said thin film layer is formed from a silicon material.

25. A method of fabricating a phase shifting photomask comprising the steps of:

forming a patterned photoresistive layer over a substrate in which patterned openings expose portions of said underlying substrate;

etching said exposed portions of said substrate to form vertical trenches in said substrate, said trenches functioning as phase shifting regions of said photomask;

depositing a thin film layer over said photoresistive layer and said substrate, including within said vertical trenches;

applying a physical force to dislodge said patterned photoresistive layer which removal also dislodges portions of said thin film layer overlying said photoresistive layer;

Wherein said thin film layer is utilized for absorbing at least a portion of light energy impinging on sidewalls of said vertical trenches in order to inhibit light scattering at said sidewalls such that resolution of a projected image field of said photomask is improved.

26. The method of Claim 25 wherein said thin film layer is deposited to a thickness of 100-500 angstroms.

27. The method of Claim 26 wherein said thin film layer is formed from a metallic material.

28. The method of Claim 26 wherein said thin film layer is formed from a silicon material.

29. A method of fabricating a phase shifting photomask comprising the steps of:

forming a patterned photoresistive layer over a substrate having opaque regions disposed thereon and in which patterned openings expose portions of said underlying substrate;

etching said exposed portions of said substrate to form vertical trenches in said substrate, said trenches functioning as phase shifting regions of said photomask;

depositing a thin film layer over said photoresistive layer and said substrate, including within said vertical trenches;

applying a physical force to dislodge said patterned photoresistive layer which removal also dislodges portions of said thin film layer overlying said photoresistive layer;

Wherein said thin film layer is utilized for absorbing at least a portion of light energy impinging on sidewalls of said vertical trenches in order to inhibit light scattering at said sidewalls such that resolution of a projected image field of said photomask is improved.

30. The method of Claim 29 wherein said thin film layer is deposited to a thickness of 100-500 angstroms.

31. The method of Claim 30 wherein said thin film layer is formed from a metallic material.

32. The method of Claim 30 wherein said thin film layer is formed from a silicon material.

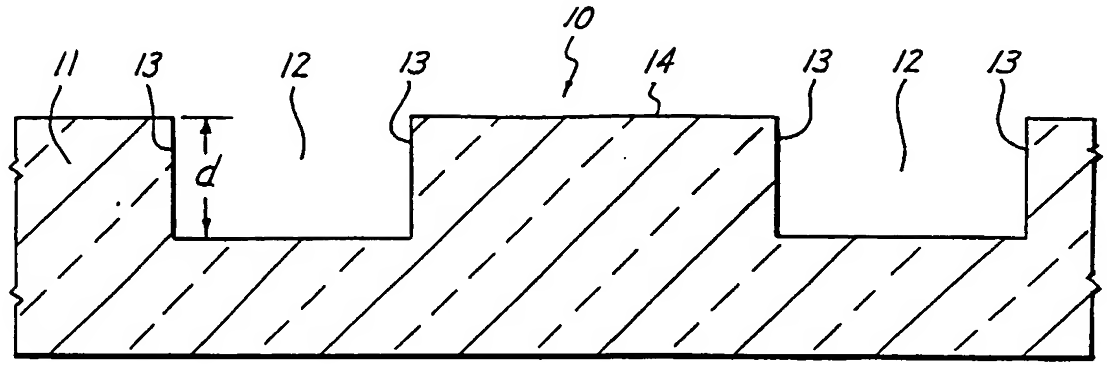
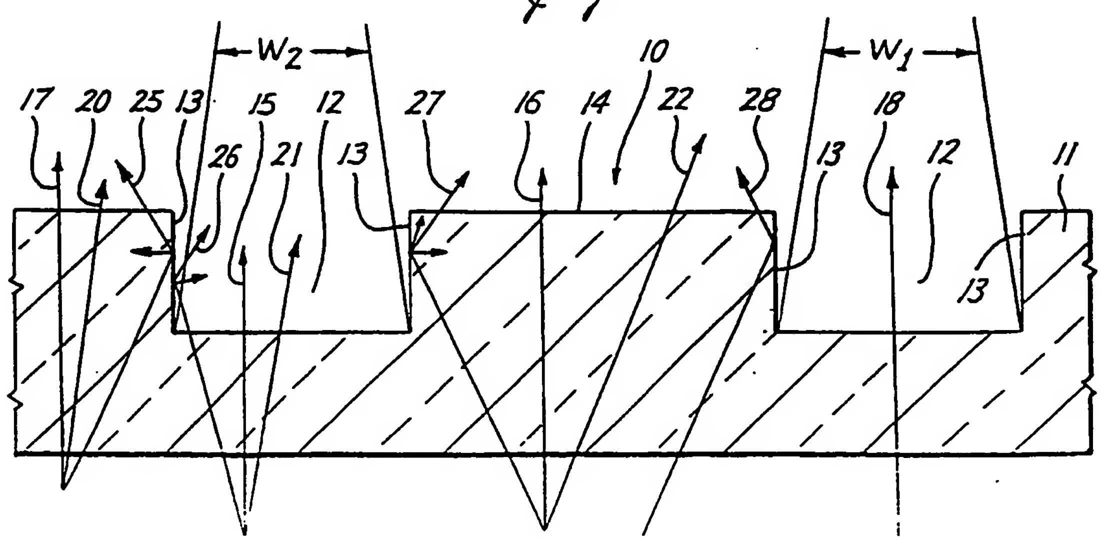


Fig. 1A

PRIOR ART

Fig. 1B



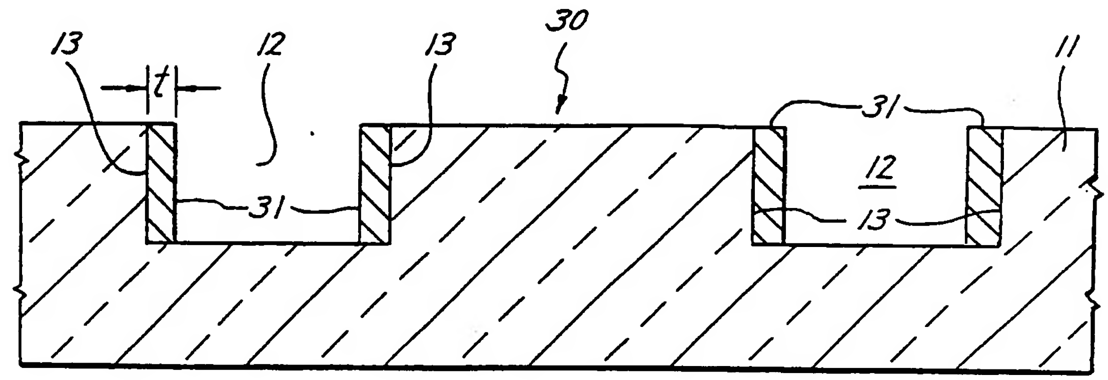

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Fig. 2A

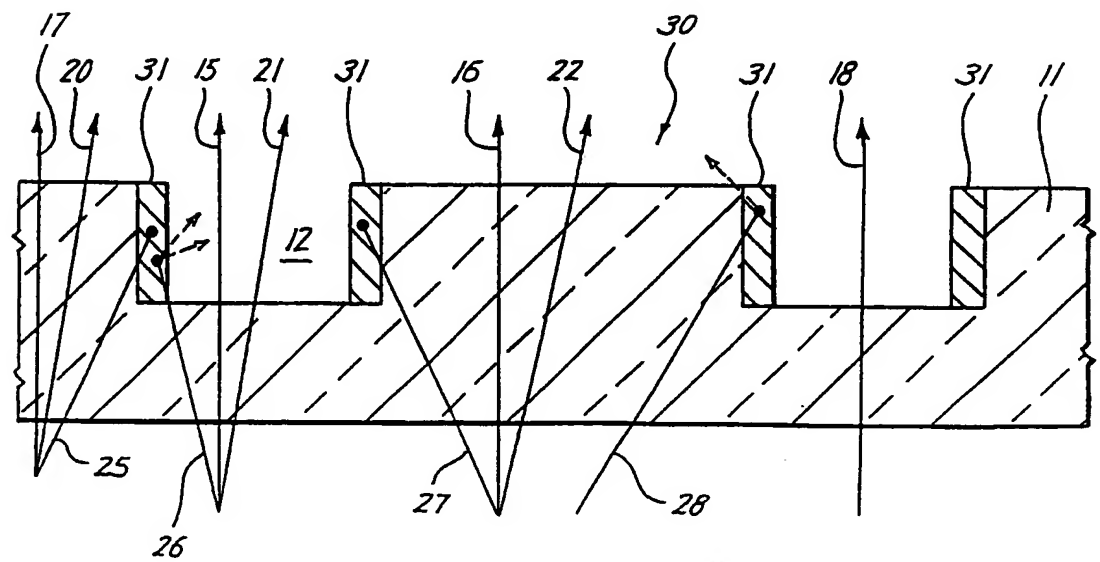
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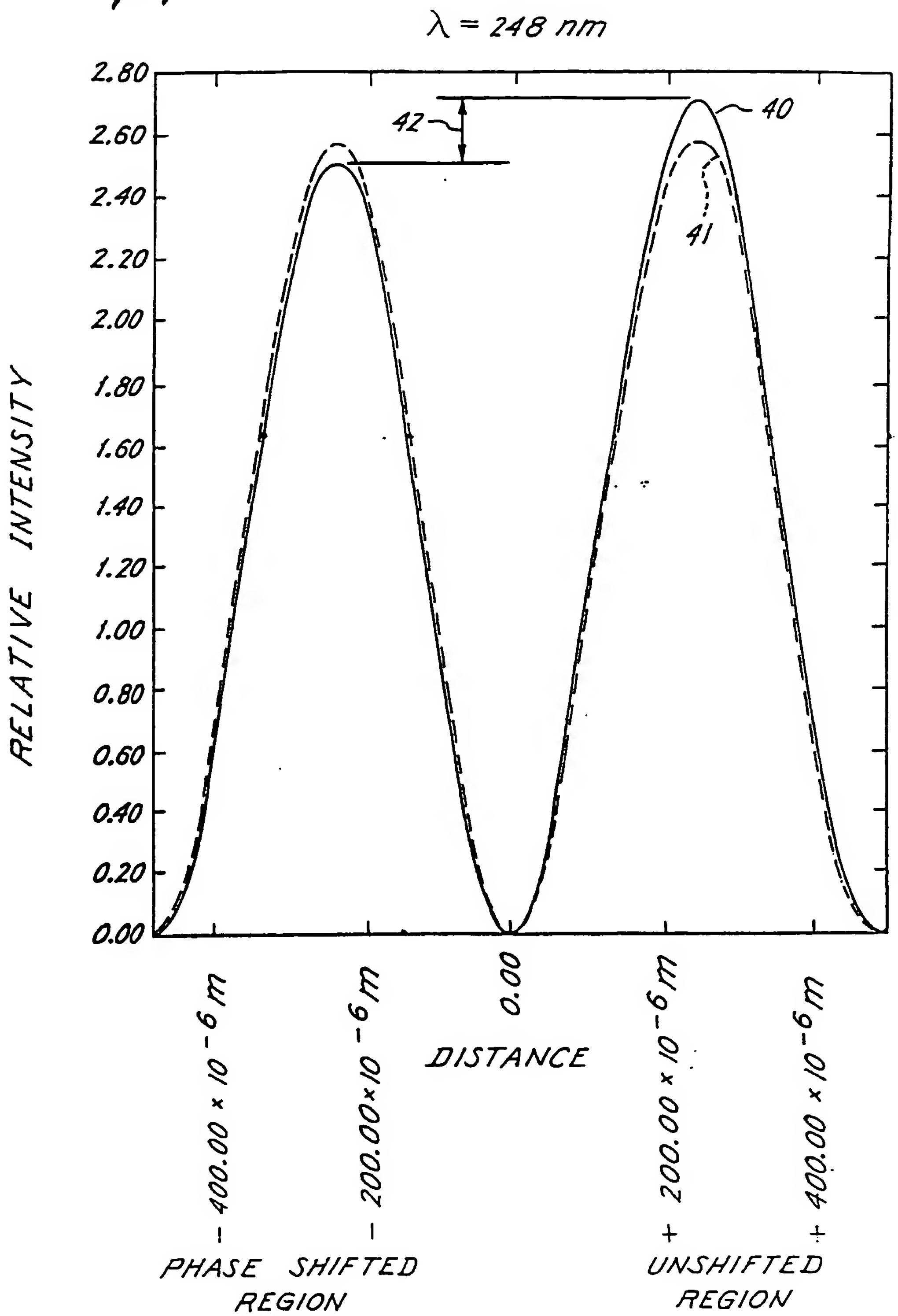
Fig. 2B

3/7

Fig. 3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2.60
2.40
2.20
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
RELATIVE INTENSITY
42
40
41
- 400.00 × 10 -6 m
- 200.00×10 -6 m
0.00
+ 200.00 × 10 -6 m
+ 400.00 × 10 -6 m
DISTANCE
PHASE SHIFTED REGION
UNSHIFTED REGION

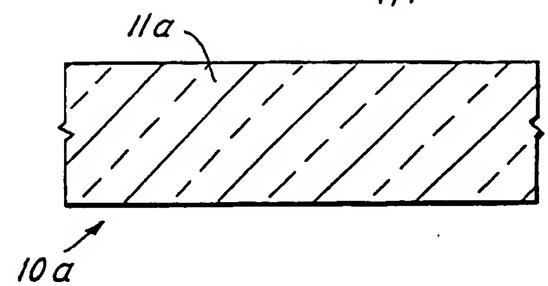

Fig. 4A

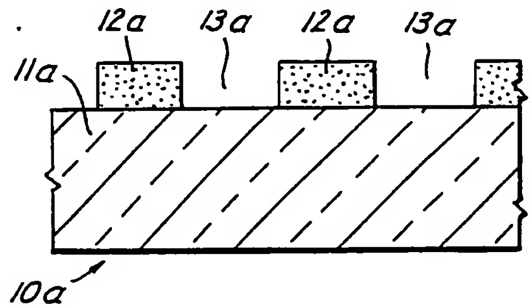

Fig. 4B

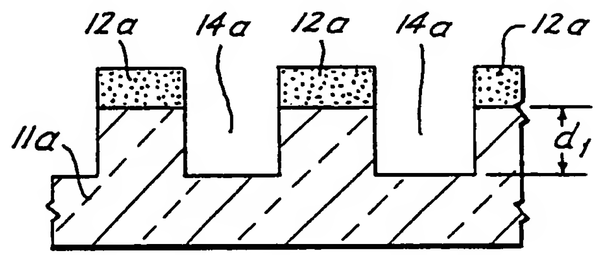

Fig. 4C

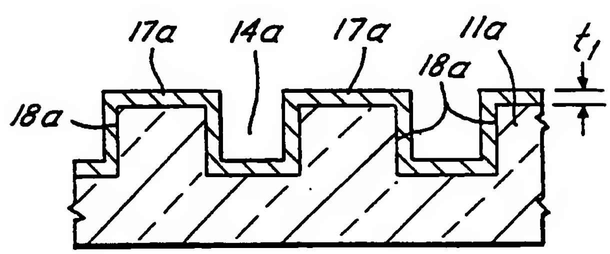

Fig. 4D

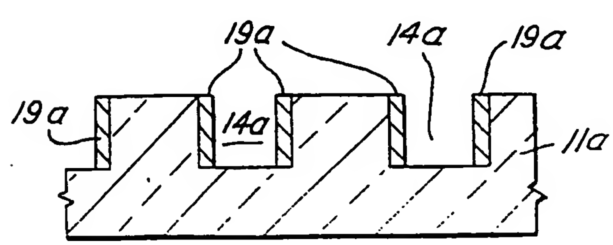

Fig. 4E

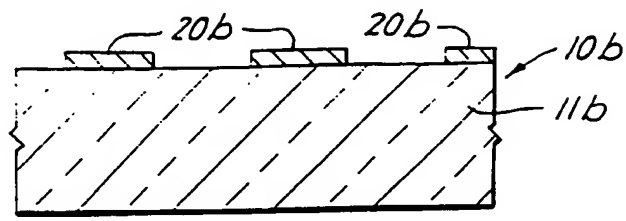

Fig. 5A

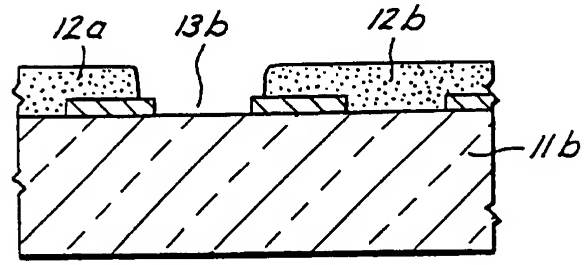

Fig. 5B

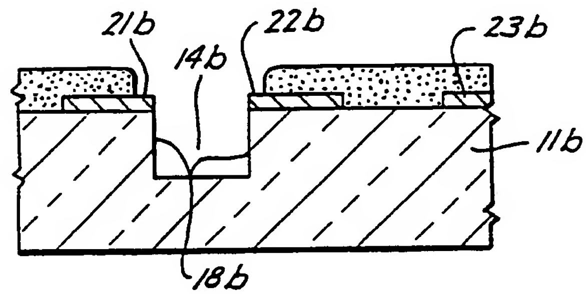

Fig. 5C

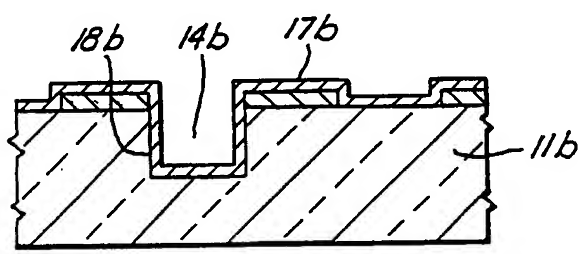

Fig. 5D

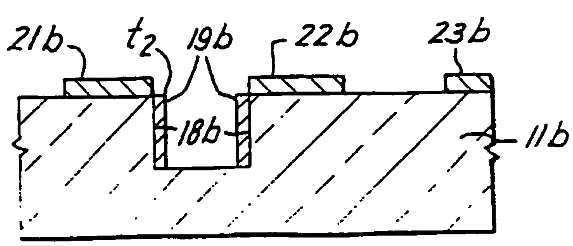

Fig. 5E

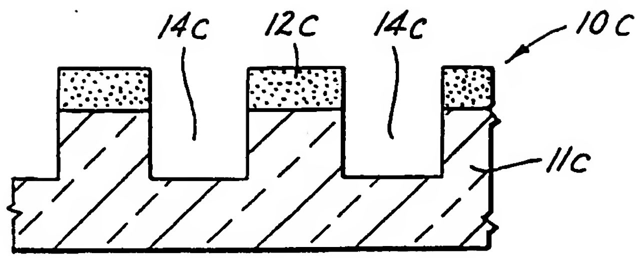

Fig. 6A

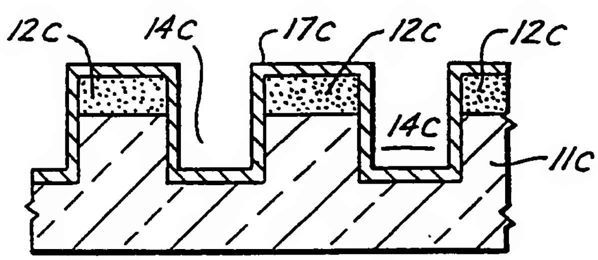

Fig. 6B

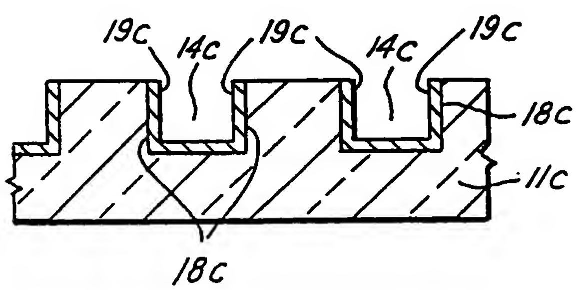

Fig. 6C

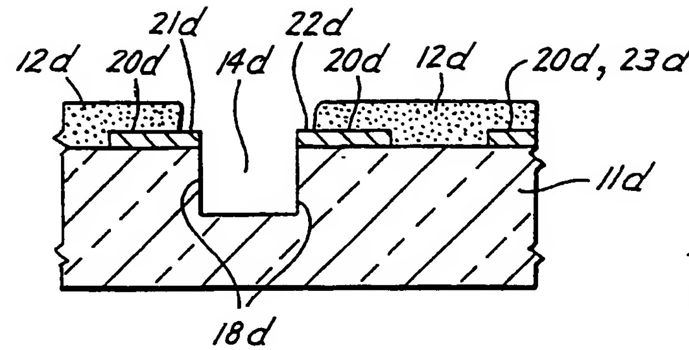

Fig. 7A

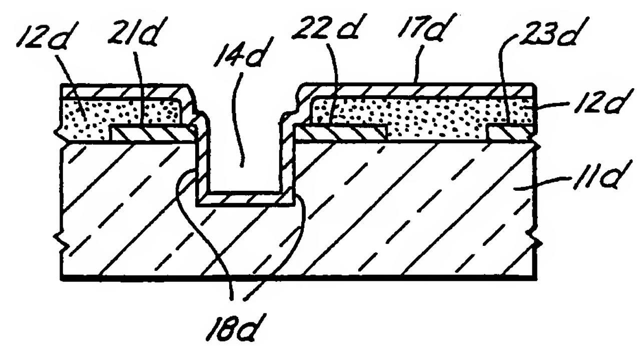

Fig. 7B

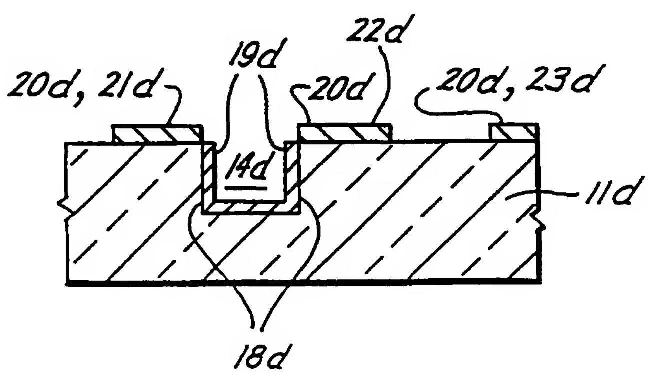

Fig. 7C

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 93/12094

A. CLASSIFICATION OF SUBJECT MATTER
IPC 5 G03F1/14 G03F7/09

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 5 G03F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP,A,3 252 659 (MITSUBISHI ELECTRIC CORP) 11 November 1991	1-3,5,6, 11,12, 14,15
Y	see figures 3A-3G	17,21, 25,29
P,X	US,A,5 219 686 (KAMON) 15 June 1993 see column 4, line 40 - column 5, line 3; figures 5A-5G	1-3,5,6, 11,12, 14,15
Y	EP,A,0 395 425 (FUJITSU LIMITED) 31 October 1990 see the whole document	17,21, 25,29

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

* Special categories of cited documents :

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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"&" document member of the same patent family

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Date of the actual completion of the international search	Date of mailing of the international search report
15 March 1994	29.03.94

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax (+31-70) 340-3016	Barathe, R

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 93/12094

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

	Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
6	Y	PATENT ABSTRACTS OF JAPAN vol. 17, no. 257 (E-1368)20 May 1993 & JP,A,05 003 146 (HITACHI LTD) 8 January 1993 see abstract ---	17,21,25
8	Y	US,A,4 119 483 (HUBERTUS HÜBSCH ET AL.) 10 October 1978 see column 1; figures 3A-D see column 4 ---	25,29
7	Y	IBM TECHNICAL DISCLOSURE BULLETIN. vol. 29, no. 3 , August 1986 , NEW YORK US page 1328 'METHOD TO PRODUCE SIZES IN OPENINGS IN PHOTO IMAGES SMALLER THAN LITHOGRAPHIC MINIMUM SIZE' see the whole document ---	17,21
7	A	IBM TECHNICAL DISCLOSURE BULLETIN. vol. 25, no. 12 , May 1983 , NEW YORK US pages 6408 - 6414 'OPTICAL RECORDING DISC SYSTEM AND MEMORY MEDIUM' see page 6408 ---	4,8
1	A	INTERNATIONAL CONFERENCE ON MICROLITHOGRAPHY, ROME, ITALY, 17-19 SEPT. 1991, 79 - 85 ISSN 0167-9317 pages 79 - 86 Lin B J 'The optimum numerical aperture for attenuated phase-shifting masks' ---	
2	A	EP,A,0 475 694 (FUJITSU LIMITED) 18 March 1992 see figure 3A ---	
2	A	US,A,5 045 417 (OKAMOTO) 3 September 1991 see column 4, line 17 - line 39; figure 12 ---	
6	A	PATENT ABSTRACTS OF JAPAN vol. 16, no. 382 (P-14382)14 August 1992 & JP,A,04 123 060 (FUJITSU LTD) 23 April 1992 see abstract -----	

4

INTERNATIONAL SEARCH REPORT

Information on patent family members

Inter nal Application No
PCT/US 93/12094

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